
Integrating Risk and Decision Analysis to Guide Restoration and Management of Contaminated Sediments

Todd S. Bridges, Ph.D.

Director - Center for Contaminated Sediments

Gregory A. Kiker, Ph.D.

Environmental Risk and Decision Analysis Team Leader

U.S. Army Engineer Research and Development Center

US Army Corps of Engineers

Waterways Experiment Station, Vicksburg MS

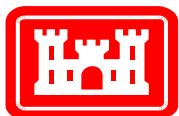


Assessment

Management

Risk —————→ **Risk**

Uncertainty —————→ **Uncertainty**



Risk

- Prediction about an adverse outcome
- Can be reduced, but not eliminated
- Larger risks motivate more aggressive remedial designs

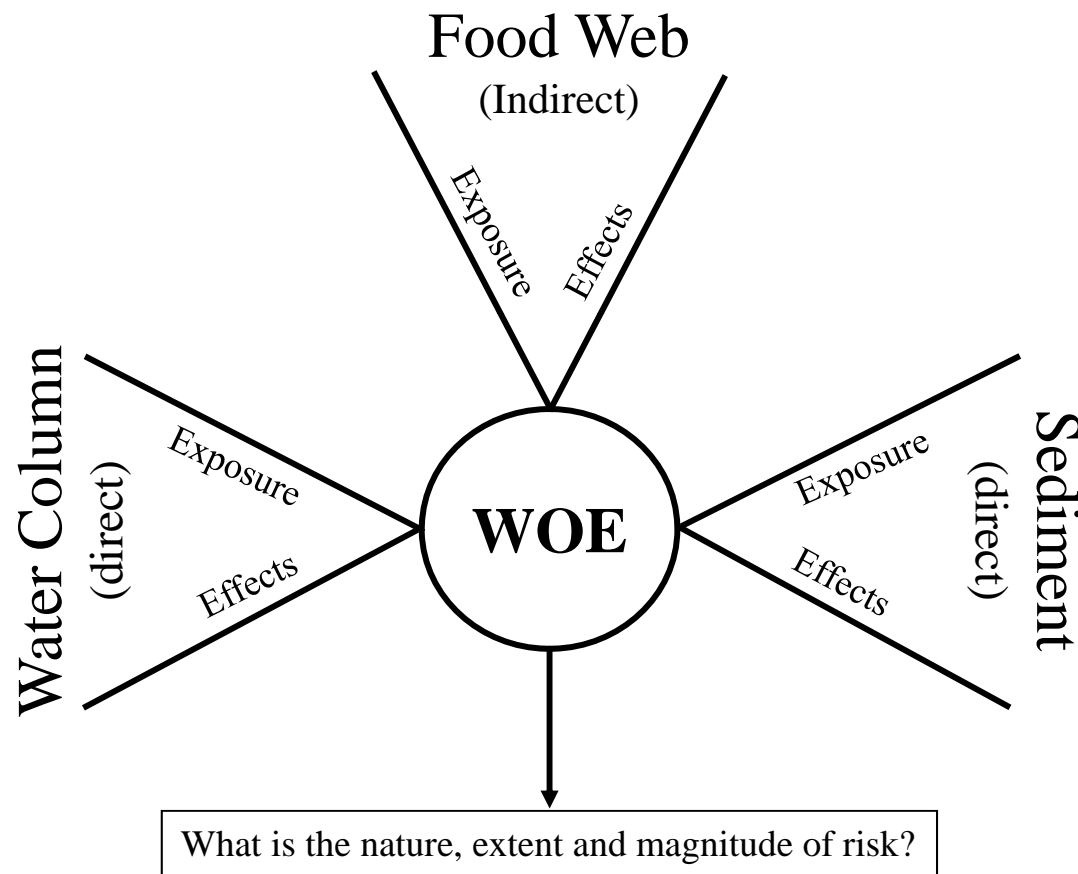
Uncertainty

- Lack of confidence in a prediction
- Can be reduced, but not eliminated
- Larger uncertainties motivate more aggressive remedial designs

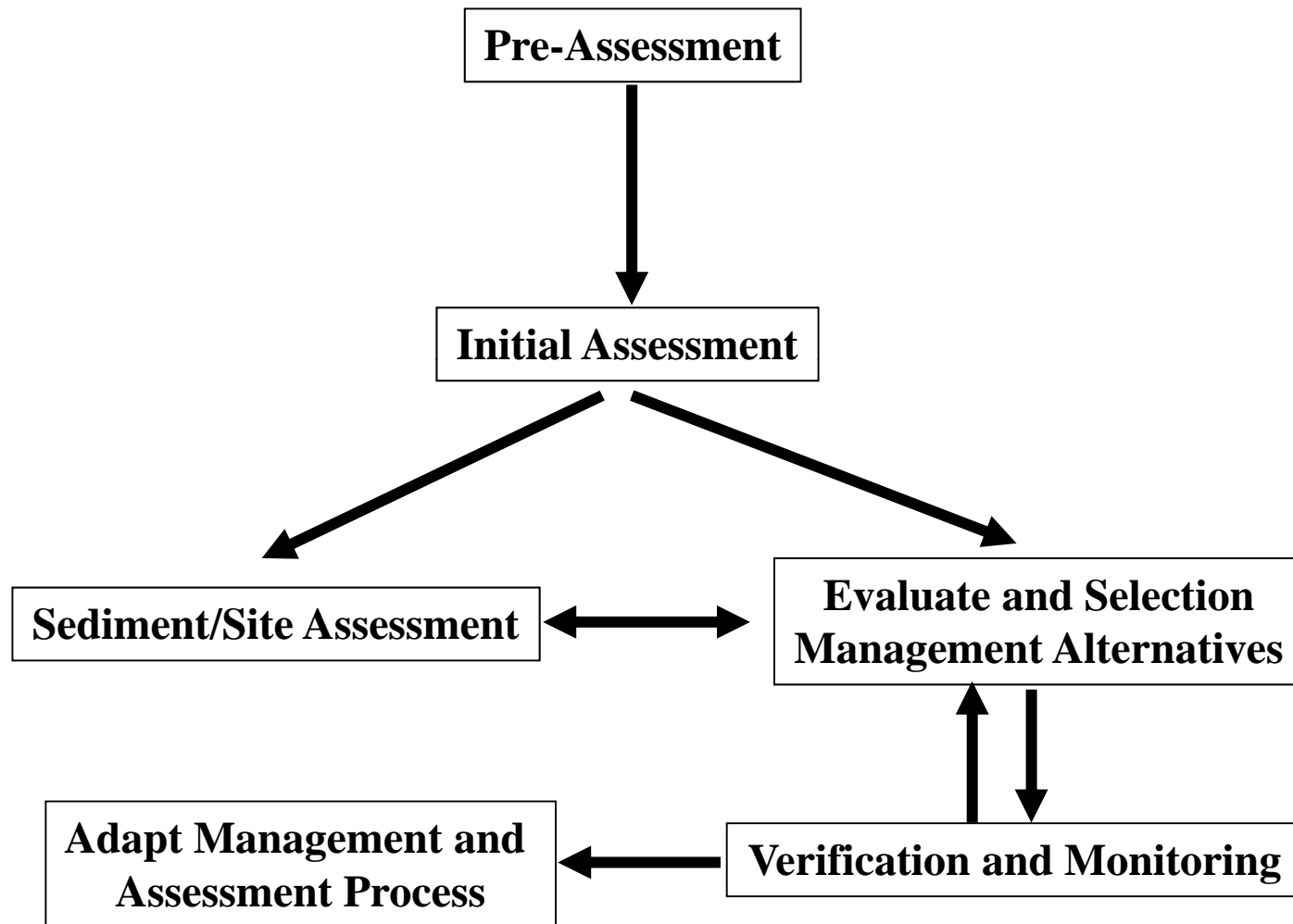
But is this sensible?



Risks Posed by Contaminated Sediment



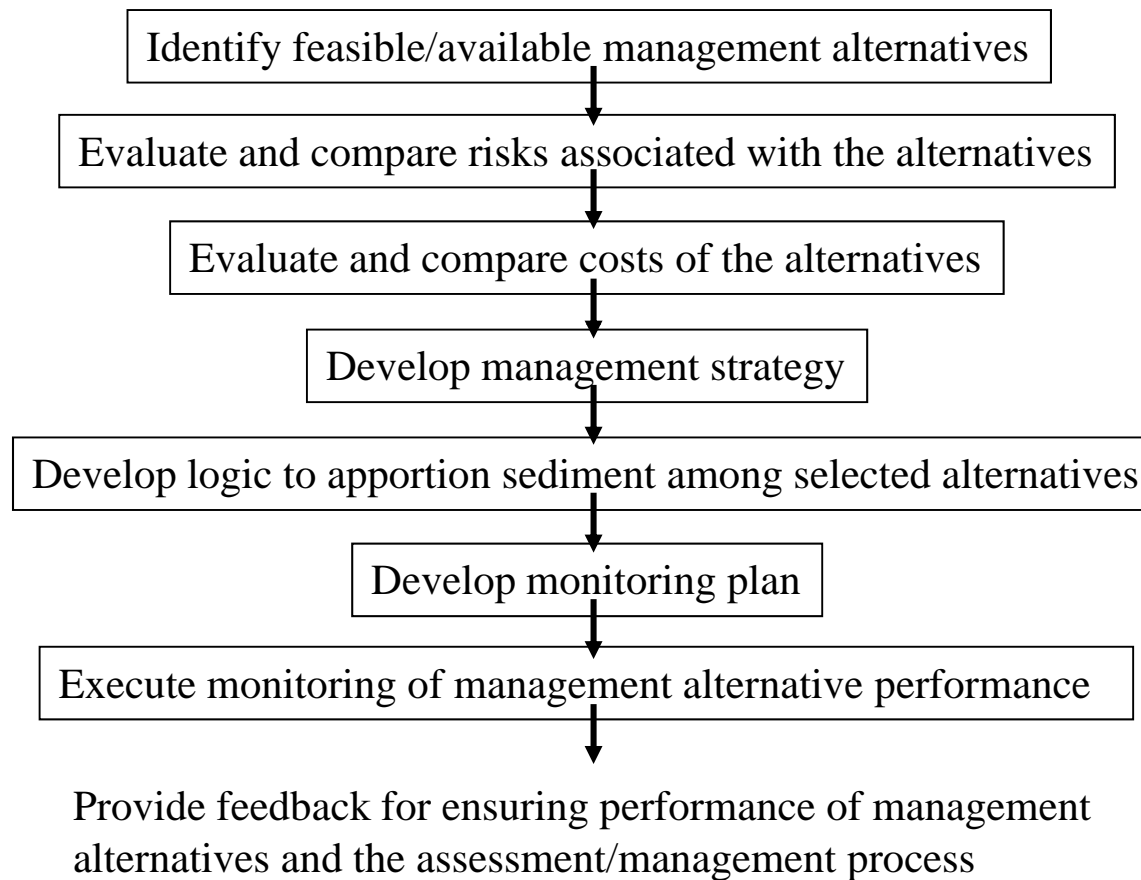
An Assessment and Management Framework



*From Bridges et al., in press



Evaluation and Selection of Management Alternatives



*From Bridges et al., in press

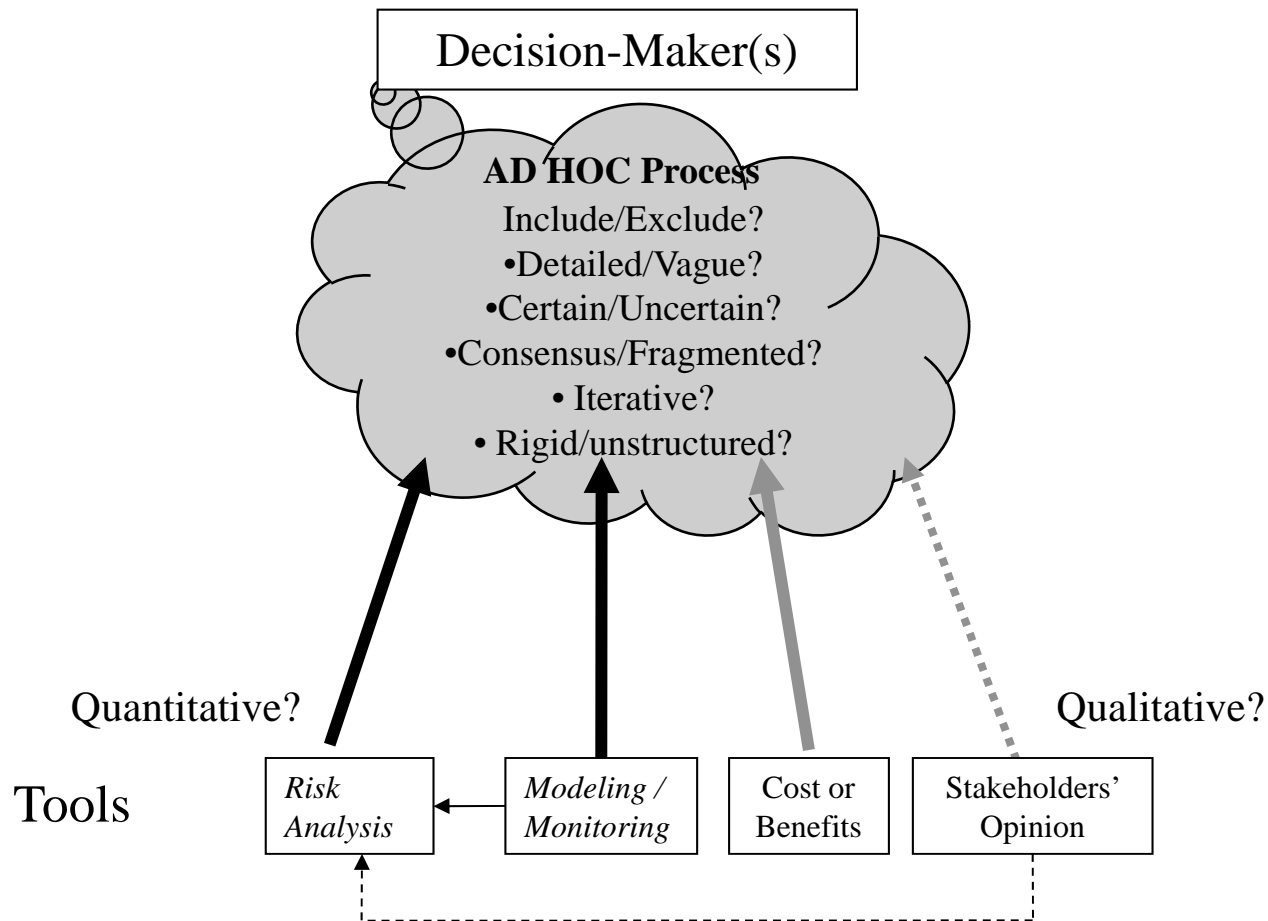


Integrating Risk and MCDA

- **Environmental assessment and decisions are growing more complex**
- **Decision Analysis Methodologies and Tools**
 - **Provide a means of integrating/comparing performance measures and decision criteria with stakeholder and decision-maker values**
 - ♦ **Multi-Criteria Decision Analysis**
 - ♦ **Example: NY/NJ Harbor**
 - **Provide a means of communicating and comparing trade-offs for planning and further understanding**
- **The Way Forward...**



Challenges in Current Decision-Making Processes

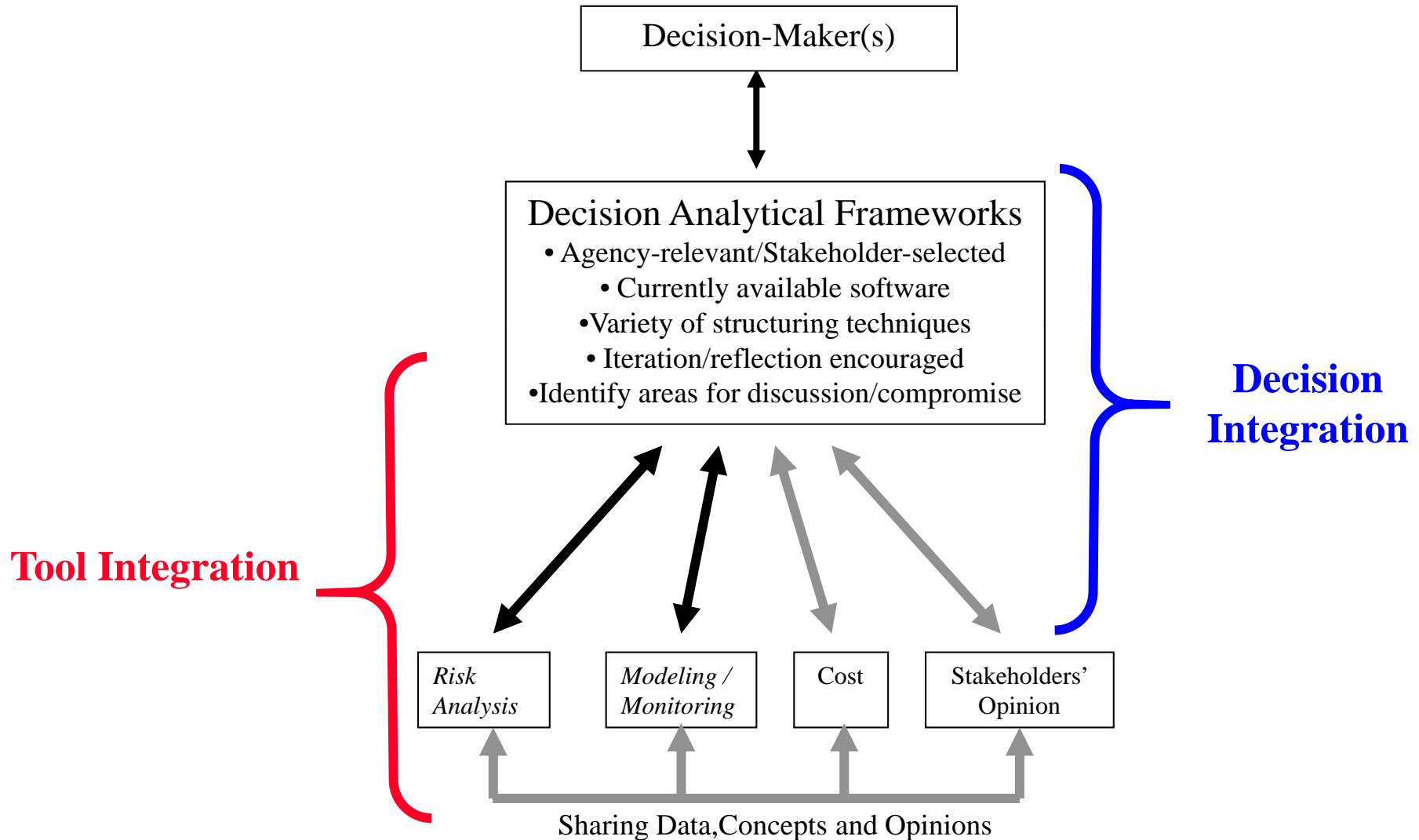


Challenges to Complex Decision-making

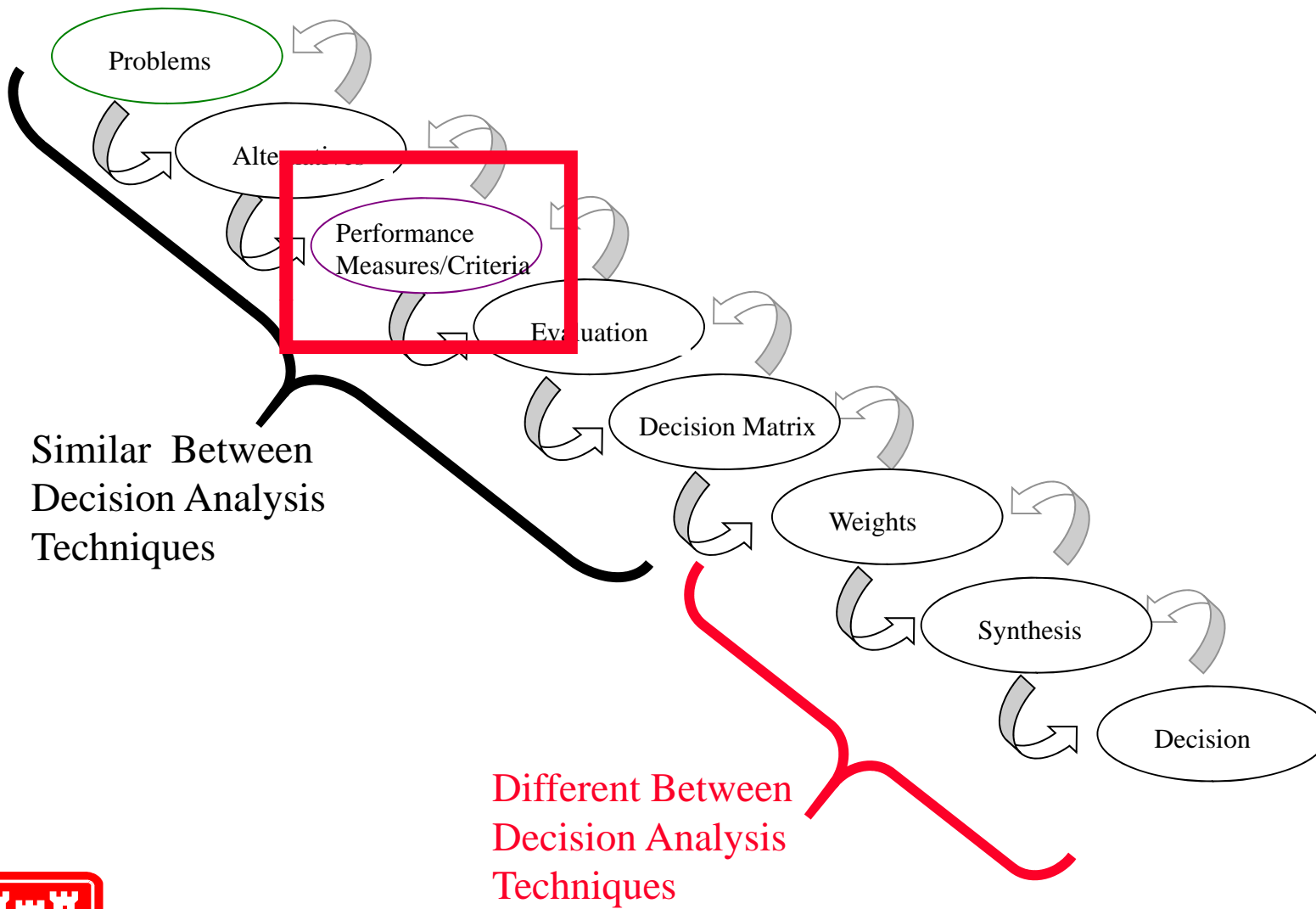
- **“Humans are quite bad at making complex, unaided decisions” (Slovic et al., 1977).**
- **Individuals respond to complex challenges by using intuition and/or personal experience to find the easiest solution.**
- **At best, groups can do about as well as a well-informed individual if the group has some natural systems thinkers within it.**
- **Groups can devolve into entrenched positions resistant to compromise**
- **“There is a temptation to think that honesty and common sense will suffice” (IWR-Drought Study p.vi)**



Evolving Decision-Making Processes



Multi-Criteria Decision Analysis (Yoe, 2002)

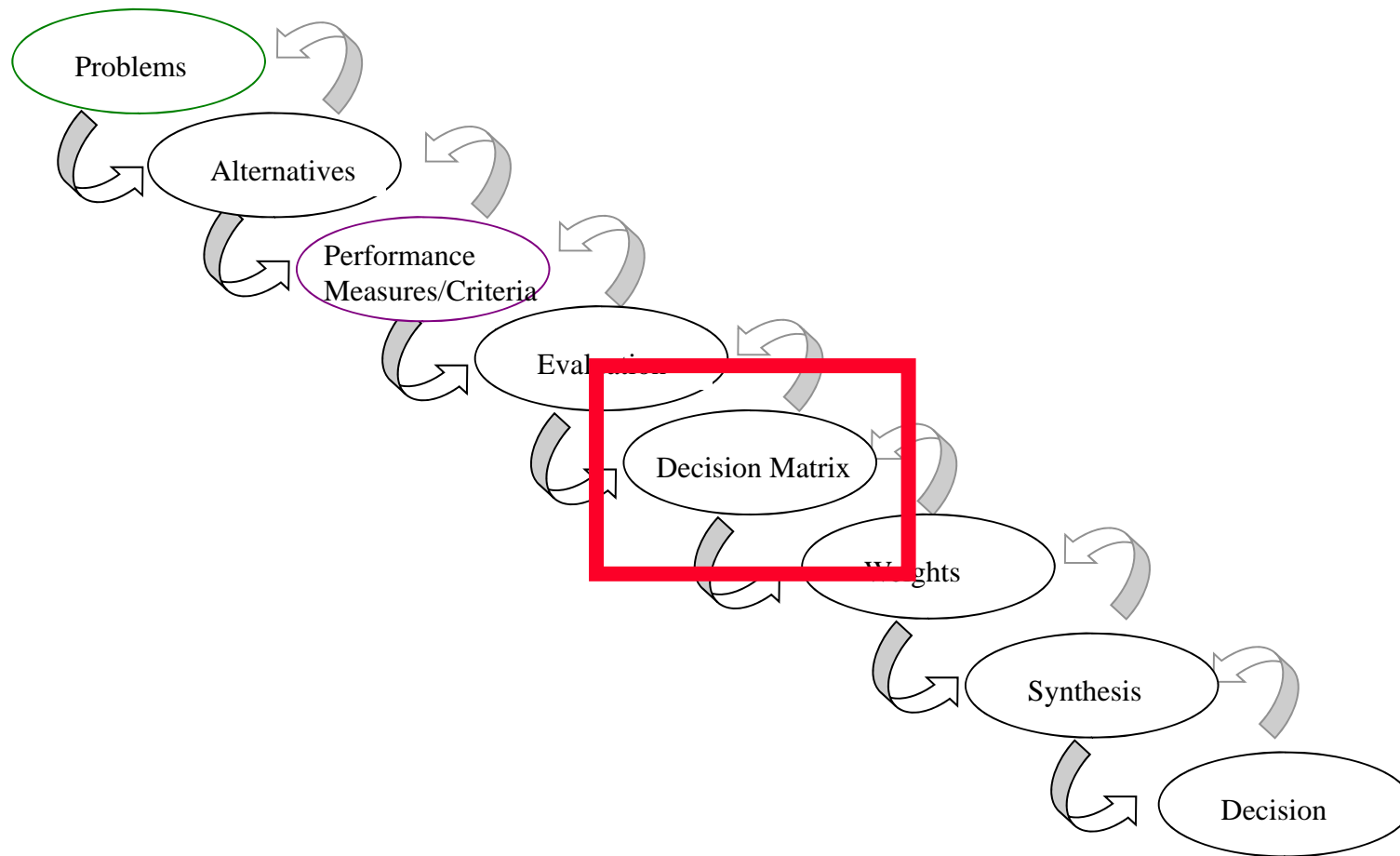


Requirements for Decision Criteria/Performance Measures

- **A coherent criteria set is: (Roy, 1985)**
 - **Exhaustive (nothing important left out)**
 - **Consistent (no secret preferences)**
 - **Non-redundant (no double counting)**
- **Effective criteria are: (Yoe, 2002)**
 - **Directional (maximum, minimum or optimum)**
 - **Concise (smallest number of measures)**
 - **Complete (no significant impact left out)**
 - **Clear (understandable to others)**
- **Criteria are often correlated but can still be acceptable**
- **Criteria should be tested throughout the decision process**



Multi-Criteria Decision Analysis (Yoe, 2002)



Current Challenge: Comparing Apples and Oranges (or Fish, Ducks and Money)

Plan	Cost	Fish	Ducks
A	100	10	5
B	100	5	10
C	150	10	10
D	150	10	15

After Yoe (2002)



Example Decision Matrix

How to combine these criteria?

How to compare these alternatives?

		Criteria 1	Criteria 2	Criteria 3	Criteria 4
Alt. 1	1	How to combine these results?			
Alt. 2		Model X Result	Stakeholder Preference	Economic Cost	Non-monetary benefit
Alt. 3		Model X Result	Stakeholder Preference	Economic Cost	Non-monetary benefit
Alt. 4		Model X Result	Stakeholder Preference	Economic Cost	Non-monetary benefit

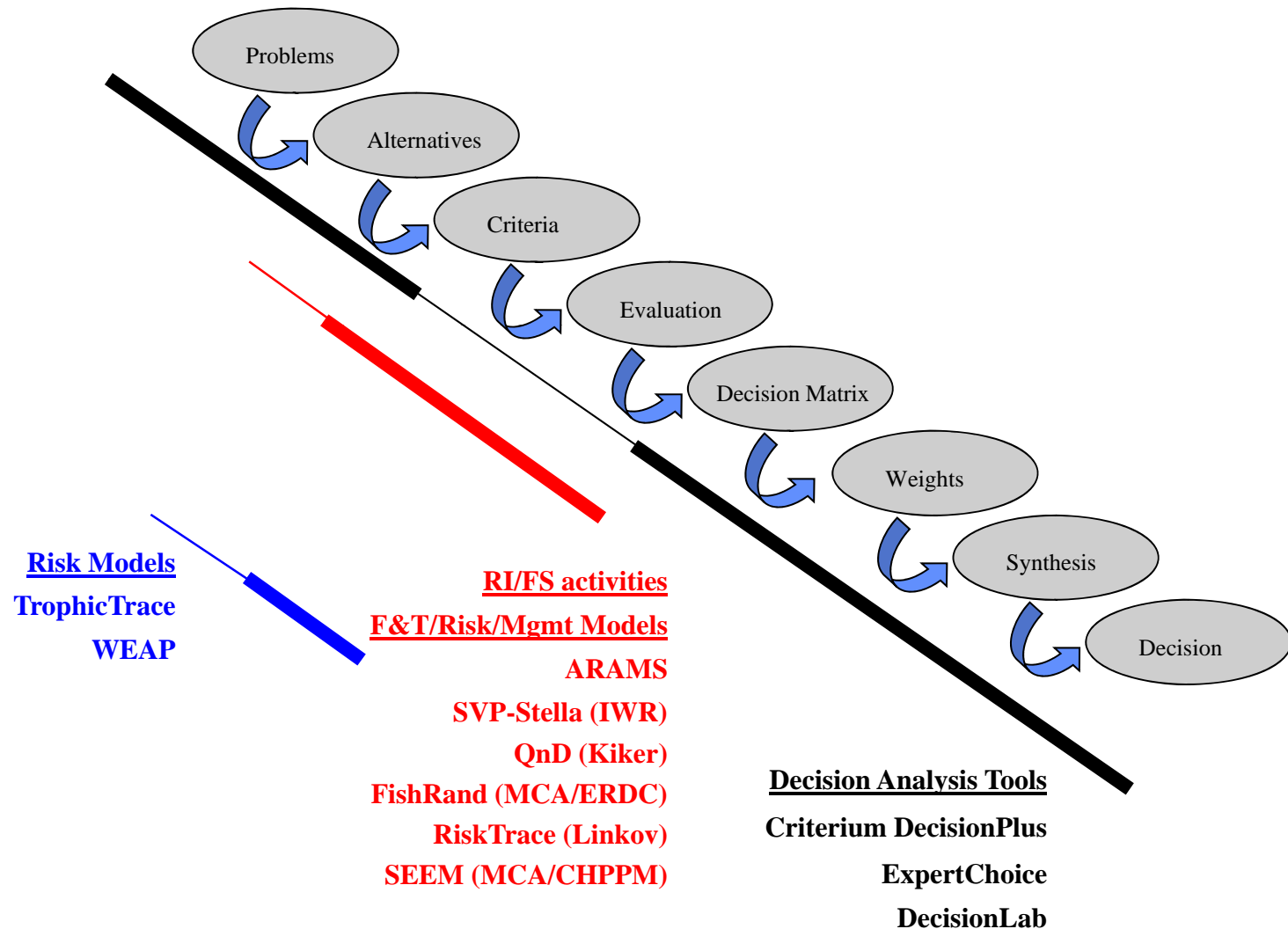


Trade-Offs: Giving up one thing to get another

- **Explicit trade-offs**
 - **Flood control vs hydropower**
 - **More of one means less of the other**
- **Implicit trade-offs**
 - **“Habitat cohesion” vs “enhancing aquatic ecosystems”**
 - **Terms of trade are not following physical laws**
- **Value trade-offs**
 - **100 acres of woodland vs 100 acres of inaccessible wetland**
 - **Choice may depend on what each person “values”**
- *Good trade-off analysis makes the “implicit” things into “explicit” things*



Tools for Planning/Decision Analysis



Example: NY/NJ Harbor



US Army Engineer Research and Development Center

18

R2-0002714

Example: NY/NJ Harbor

Issues

- Harbor among most polluted in U.S.
- $>10^6$ yd³ fail regional criteria for ocean disposal
- Existing disposal site closed 1 Sep. 97
- Proposed deepening

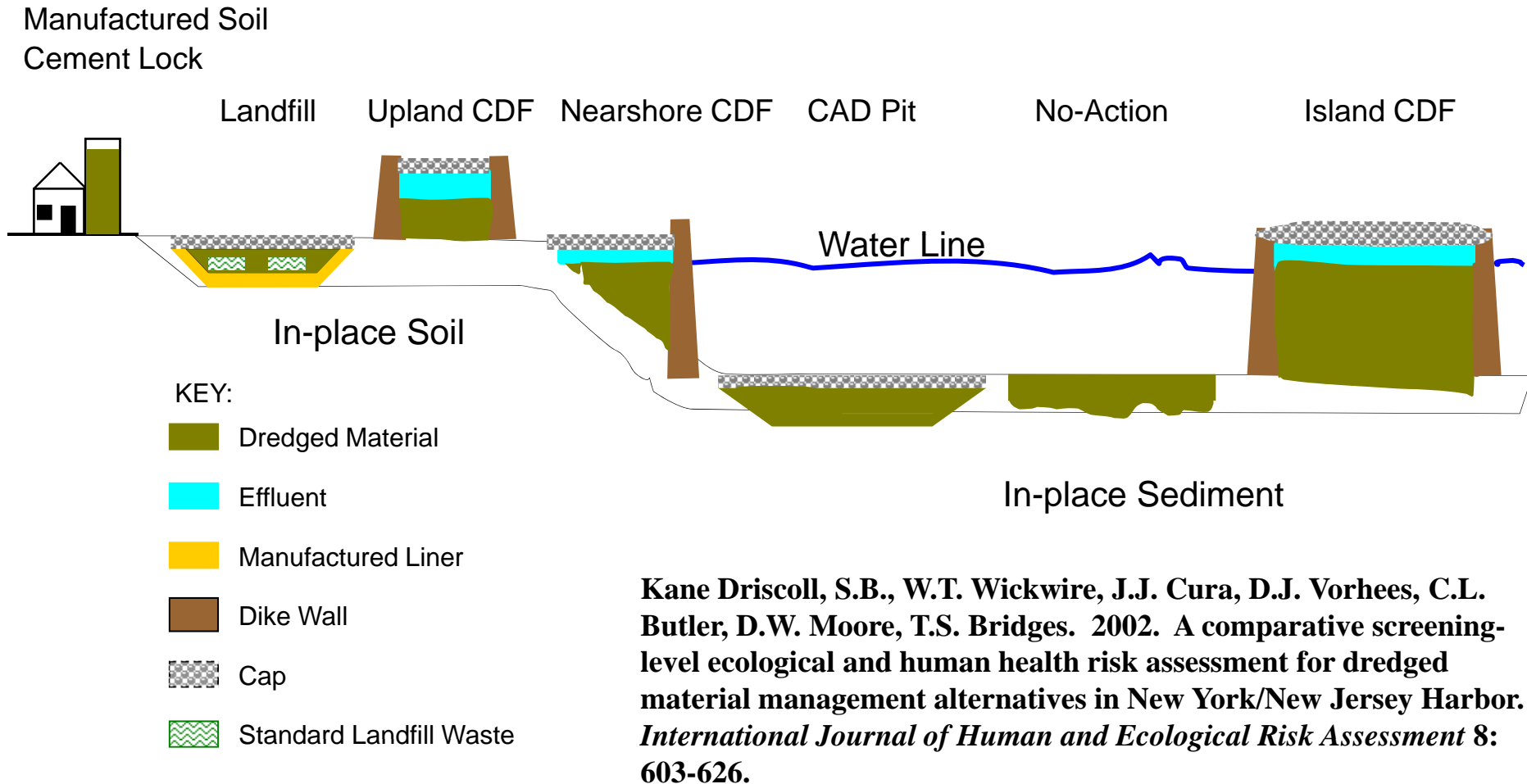


Example: Decision Methodology

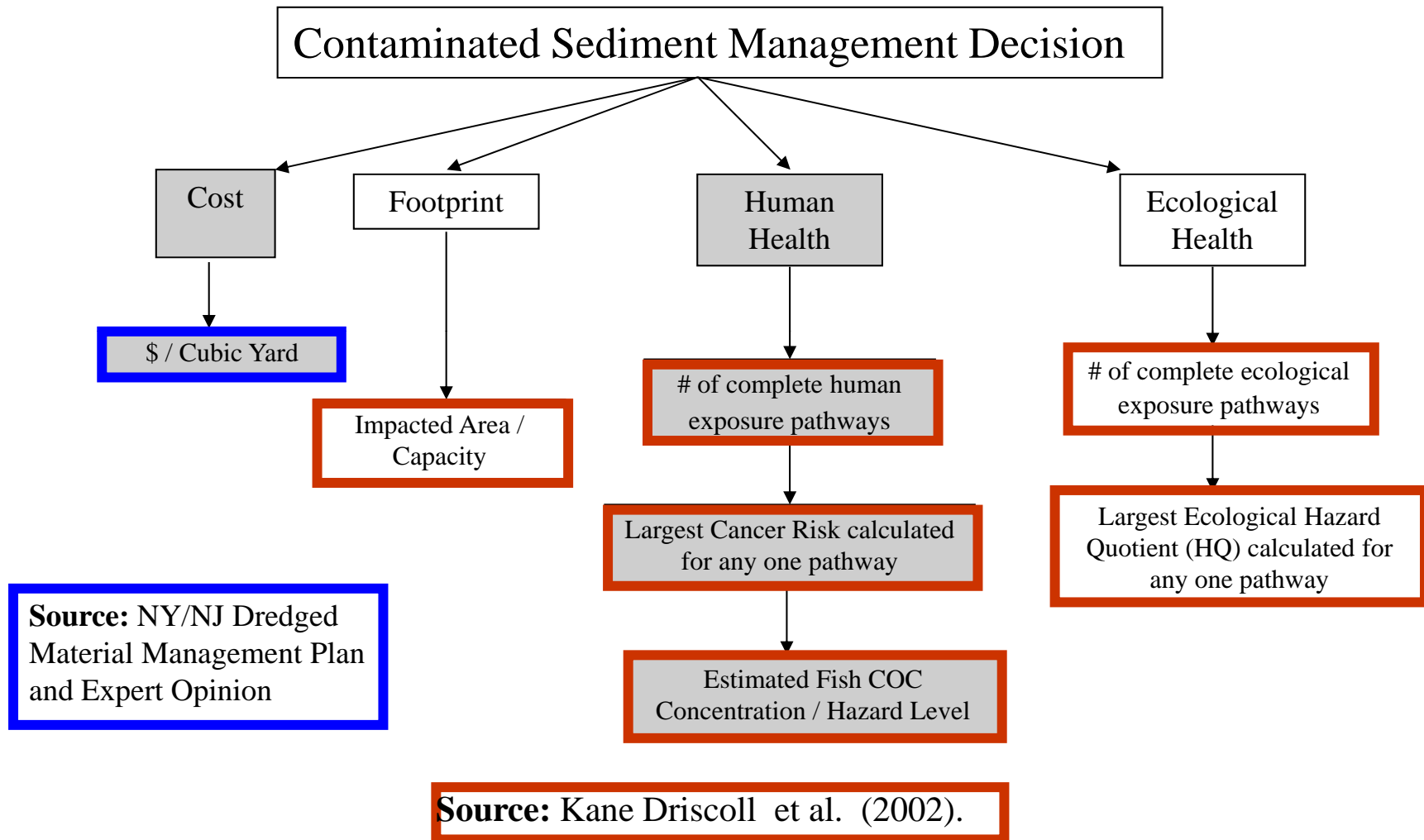
- **Proof of Concept Study**
- **Objectives**
 - **Integrate comparative risk assessment results with cost and stakeholder decision criteria**
 - **Use decision criteria/performance measures from published data and proposed costs**
 - **Test decision tools, methodology and results**
- **Set contaminated sediment management options**
- **Set decision criteria/performance measures**
- **Software - Criterium DecisionPlus**
- **Stakeholder Values / Expert Surveys**
 - **USACE/EPA dredged material managers meeting (March 2004)**
 - **Selected NY/NJ harbor stakeholders (USACE, EPA, Port Authorities, State, NGOs) (June 2004)**



Conceptual Illustration of Disposal Alternatives



Decision Criteria: NY/NJ Harbor



Criteria Levels for Each DM Alternative

DM Alternatives	Cost	Footprint	Ecological Risk		Human Health Risk		
	(\$/CY)	Impacted Area/Capacity (acres / MCY)	Ecological Exposure Pathways	Magnitude of Ecological HQ	Human Exposure Pathways	Magnitude of Maximum Cancer Risk	Estimated Fish COC / Risk Level
CAD	5-29	4400	23	680	18	2.8 E -5	28
Island CDF	25-35	980	38	2100	24	9.2 E -5	92
Near-shore CDF	15-25	6500	38	900	24	3.8 E -5	38
Upland CDF	20-25	6500	38	900	24	3.8 E -5	38
Landfill	29-70	0	0	0	21	3.2 E -4	0
No Action	0-5	0	41	5200	12	2.2 E -4	220
Cement-Lock	54-75	0	14	0.00002	25	2.0 E -5	0
Manufactured Soil	54-60	750	18	8.7	22	1.0 E -3	0

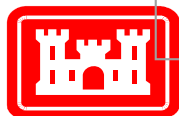
Blue Text: Most Acceptable Value

Red Text: Least Acceptable Value



USACE/EPA DM Managers Meeting: NY/NJ Harbor Weighting Form

Attribute Swung from Worst to best	Consequence to compare	Rank (1-9)	Rate (0-100)
Benchmark: Worst case on everything	Impacted Area/Capacity of Facility = 6500 (acres/ 10 ⁶ cubic yards) Magnitude of Ecological Hazard Quotient – Maximum Exposure = 5200 Number of Complete Ecological Exposure Pathways = 41 Number of Complete Human Exposure Pathways – 25 Magnitude of Maximum Cancer Probability (Non-barge worker) = 1* 10 ⁻³ Ratio of Estimated Concentration of COCs in Fish to Risk-Based Concentrations = 220 Cost = 54-75 \$/CY	9	0
Impacted Area/Capacity of Facility	Change from 6500 (acres/ 10 ⁶ cubic yards) to 0 (acres/ 10 ⁶ cubic yards)		
Magnitude of Ecological Hazard Quotient –Maximum Exposure	Change from 5200 to 0		
Number of Complete Ecological Exposure Pathways	Change from 41 to 0		
Number of Complete Human Exposure Pathways	Change from 25 to 12		
Magnitude of Maximum Cancer Probability (Non-barge worker)	Change from 1* 10 ⁻³ to 0.028 * 10 ⁻³		
Ratio of Estimated Concentration of COCs in Fish to Risk-Based Concentrations	Change from 220 to 0		
Cost	Change from (54-75 \$/CY) to (0-5 \$/CY)		

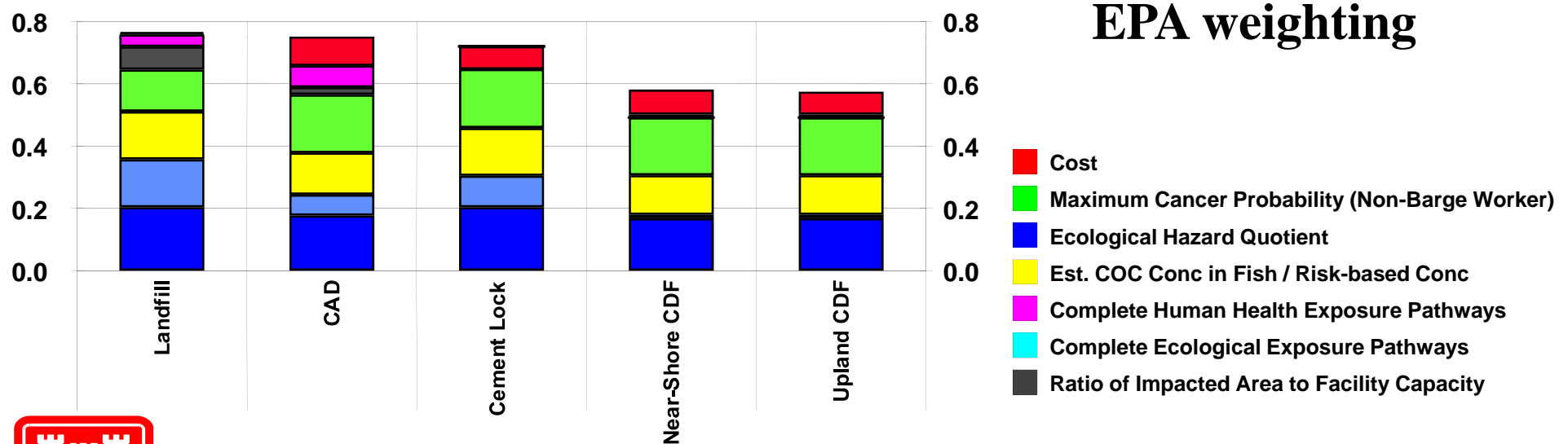
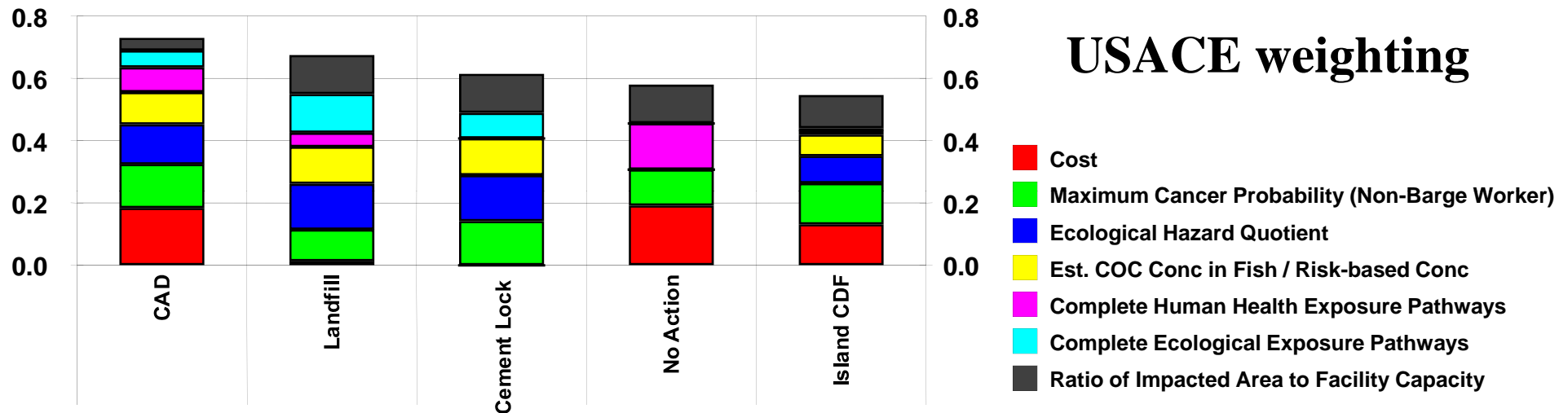


USACE/EPA Survey Results: Criteria Weights (%)

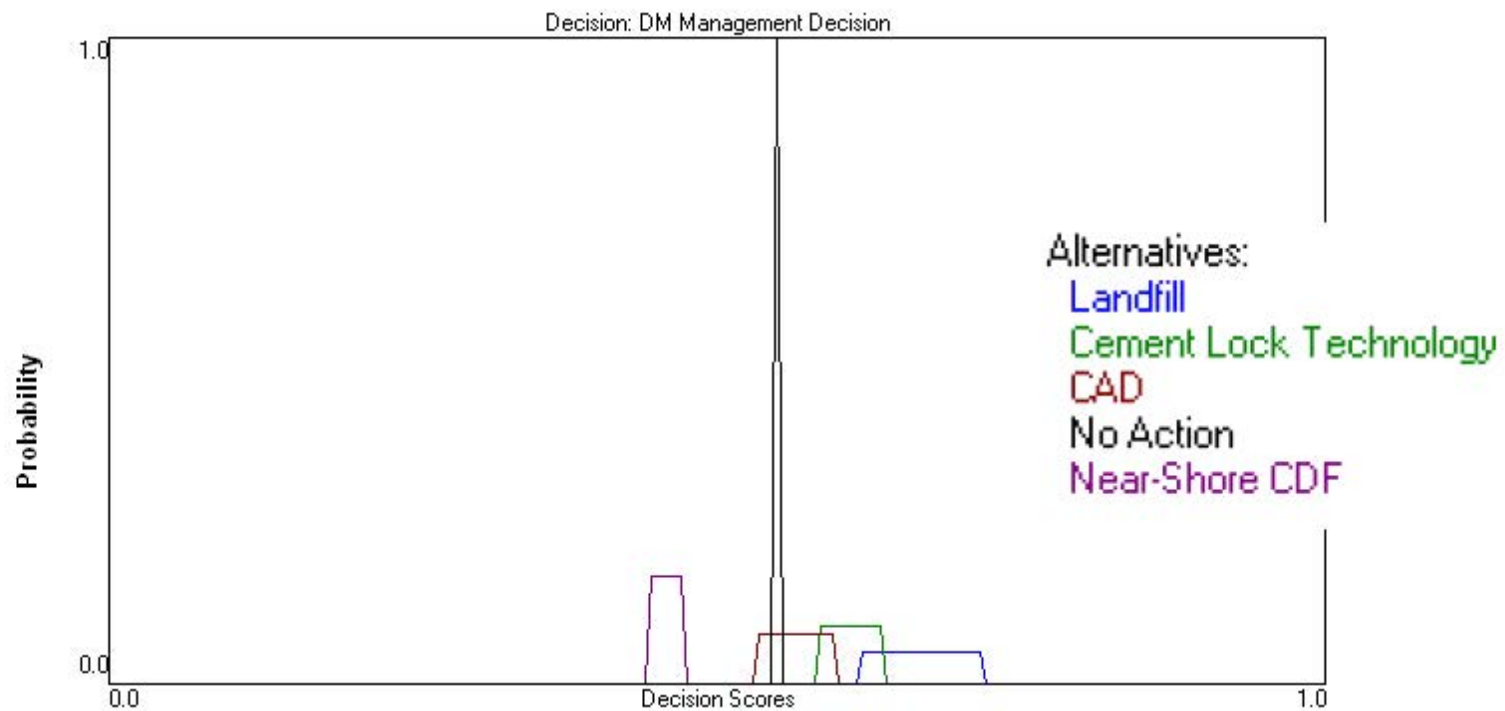
	EPA	USACE
Footprint	7.4	12.5
Ecological Health	35.6	27.1
Human Health	47.0	40.7
Cost	10.0	19.7



Criteria Contributions to Decision Score

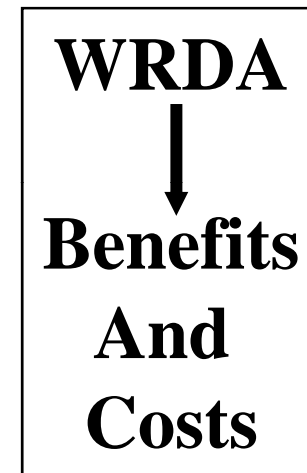


The Role of Uncertainty



Decision Criteria

- **NCP**
 - **Threshold criteria**
 - ◆ **Protect HH and Environment**
 - ◆ **Compliance with ARARs**
 - **Balancing Criteria**
 - ◆ **Long-term effectiveness and permanance**
 - ◆ **Reduction of TMV through treatment**
 - ◆ **Short-term effectiveness**
 - ◆ **Implementability**
 - ◆ **Cost**
 - **Modifying Criteria**
 - **State acceptance**
 - **Community acceptance**



Summary: Essential Decision Ingredients

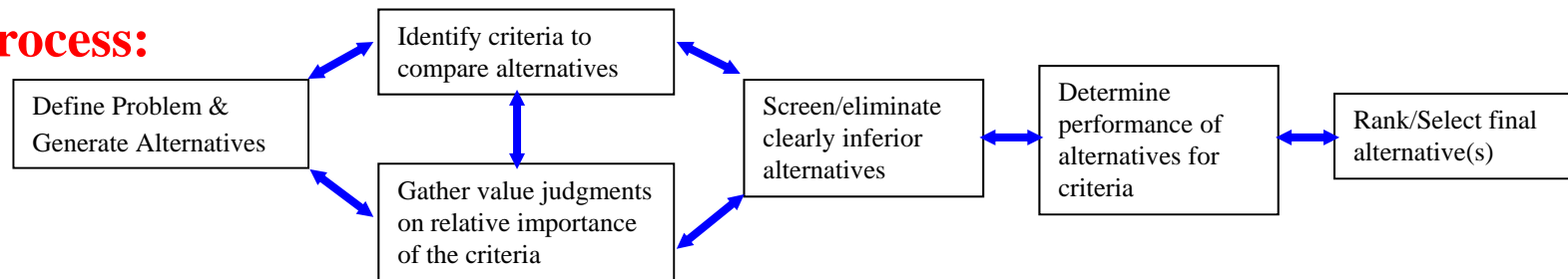
People:

Policy Decision Maker(s)

Scientists and Engineers

Stakeholders (Public, Business, Interest groups)

Process:



Tools:

Environmental Assessment/Modeling (Risk/Ecological/Environmental Assessment and Simulation Models)

Decision Analysis (Group Decision Making Techniques/Decision Methodologies and Software)

